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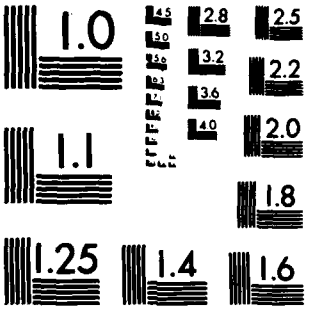


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# ONR LONDON REPORT

R-5-84

# OFFICE OF NAVAL RESEARCH

**BRANCH OFFICE LONDON ENGLAND**

EUROPEAN RESEARCH ON POLYMERS AND COMPOSITES

R.W. ARMSTRONG and
VIVIAN T. STANNETT

13 February 1984





**UNITED STATES OF AMERICA**

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This report discusses the strategies and funding for research on polymers and composites in the UK, the Federal Republic of Germany, and France.

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## EXECUTIVE SUMMARY

This report provides an overview of the support for research on polymers and composites in the UK, the Federal Republic of Germany (FRG), and France.

1. Polymers

- Expenditures: £8,000,000 to £10,000,000 in the UK; DM 26,500,000 in the FRG.
- Priorities: materials for composites in the UK, FRG, and France.
- Main actors: cooperative government, university, and industrial interests.
- Strategies: strong government support of research for industry in the UK and less direction in the FRG and France.

2. Composites

- Expenditures: £3,000,000 in the UK (government only); F 550,000,000 in France (total); DM 30,000,000 in FRG (estimated 3 percent total manufacturing R&D).
- Priorities: aerospace, armament, automotive, structures.
- Main actors: government aerospace laboratories: RAE (UK), ONERA (France), and DFVLR (FRG).
- Strategies: government support of research centered on aerospace laboratories.

3. Rapid solidification

- Expenditures: not a recognized line item, except for emphasis given to the subject in France; less than £1,000,000 expenditure in the UK.
- Priorities: rapidly quenched powder product in the UK and France; emphasis on property measurement in the FRG.
- Main actors: universities and RAE in the UK; joint ONERA and nationalized company effort in France; university, industry, and DFVLR efforts in FRG.
- Strategies: some emphasis in France; in the UK and FRG, university activities are mainly under way in anticipation of future developments.

4. The UK government's support of research on these topics and others is strongly geared to direct or anticipated needs of private industry.

5. The French government's support of research is now strongly tied to the needs of their newly nationalized industries.

CONTENTS

# EUROPEAN RESEARCH ON POLYMERS AND COMPOSITES

This report provides an overview of the support for research on polymers and composites in the UK, the Federal Republic of Germany (FRG), and France.

## Polymers

### *United Kingdom*

Scale of Effort and Funding Estimate. Polymer research under government funding is conducted at the various educational institutions, in government laboratories, and, to a lesser extent, through contracts with private research institutes and with industry itself. Actual funding levels are difficult to ascertain, but the following discussion leads to a reasonable estimate.

Polymer research is being carried out at 45 universities, polytechnics, and colleges. The main funding agency is the Science and Engineering Research Council (SERC), roughly corresponding to the US National Science Foundation. In addition, there are about 16 Ministry of Defence (MoD) grants, including those from the Royal Aircraft Establishment (RAE), the Royal Signal and Radar Establishment (RSRE), the Atomic Weapons Research Establishment (AWRE), and the Propellants, Explosives and Rocket Motor Establishment (PERME). Other government agencies supporting academic research are the Ministry of Trade and Industry (MOTI) and the Atomic Energy Agency.

The SERC funding is estimated to be £400,000 (£1.00 equals about $1.45) in major grants (greater than £50,000), usually over 3 to 4 years. These grants total approximately £120,000 per year; there is another £900,000 per year in smaller grants. The SERC also sets aside an additional £2,900,000 per year for engineering research on polymers and the Polymer Engineering Directorate (PED) program. The amounts of MoD and other government grants are not known, but could be up to, say, £400,000. Thus the total support in educational institutions is approximately £4,300,000.

The Rubber and Plastics Research Association (RAPRA) receives about £500,000 in government support and about an equal amount from industry.

The level of government expenditure for polymer research in private research institutes--such as the Fulmer Research Institute--and in industry itself is not known, but could be as high as £500,000 per year.

In addition, polymer research is carried out in a number of government research establishments. The funding levels have not been revealed, but the National Physical Laboratory (NPL) estimated that it had 10 professionals working on polymers at a rough cost of £40,000 per professional, including support staff and other costs. This would suggest a figure of £400,000. Subsequent inquiries confirmed that the £40,000 figure per professional is a good approximation for all the laboratories. Inquiries have led to an estimate of six to 10 professionals per laboratory (Table 1), or £240,000 to £400,000 per year. Including NPL, this gives a total expenditure of about £3,000,000 to £5,000,000 per year. Therefore, the total government funding for polymer research in the UK is probably between £8,000,000 and £10,000,000.

Research Areas and Priorities. This section lists areas of polymer research that are of high priority for the UK government. The role of government laboratories and private industry in the research is also discussed.

1. High-strength, high-modulus fibers, including their use in composites. Two types of polymers are of special interest: (a) liquid crystalline polymers such as Kevlar, and (b) very highly oriented polymers produced by drawing techniques. In particular, polyethelene is being studied in great detail. The work appears to be mainly in the educational institutions, although the RAE might have a small effort in this field.

2. The synthesis and development of new polymeric materials for specific industrial and military applications. The work is mainly in educational institutions, with some at RAE, PERME, and possibly AMTE (materials laboratory).

Table 1

Laboratories and Estimated Professional Staffing

| | |
|---|---|
| UK Atomic Energy Agency | ~5 scientists |
| British Telecom Research Center | not known |
| National Engineering Laboratory (NEL) | ~6 engineers |
| MoD laboratories, including RAE | ~6 |
| Chemical Defense Establishment | ~2 |
| PERME | ~15 |
| AWRE | not known |
| RSRE | not known |
| Royal Military College of Science | ~5 |
| Admiralty Marine Technology Establishment (AMTE) (Materials Lab.) | ~10 |

3. Polymer blends and the fundamental problems of polymer compatibility. The work is mainly at educational institutions.

4. Surface phenomena in polymers and adhesion. The work is mainly at educational institutions, plus some in the government laboratories.

5. Innovative developments in the understanding of the structure and mechanical behavior of polymers. The work is at educational institutions and at NPL, AMTE, RAPRA, and NEL.

6. Fundamental work in the engineering of polymers--such as extrusion, molding, and related problems. The work is done at the educational institutions.

7. Polymers with novel optical and electrical properties. These include electrically conductive, piezoelectric, and pyroelectric polymers; polymers for photo x-ray and photoelectron resistant applications; and reversibly photochromic polymers, including those based on liquid crystals. The work is done at educational institutions, AERE, British Telecom, RSRE, and AWRE; the relative levels are not known. This is also a very active area in the UK industrial laboratories--but mainly without direct government funding.

8. Fire-resistant polymers, including the effect of additives. The work is done at the universities, particularly the City University (London) and Edinburgh; at the Admiralty Marine Technology Works (AMTW), Portsmouth; and at the Fire Research Station of the Building Research Establishment, Boreham-wood, Hertfordshire.

Polymer research in private industry is in general at a low level, although there are at least two important exceptions. Imperial Chemical Industries (ICI) and British Petroleum (BP) have highly sophisticated and large research efforts ranging from the fundamental to the highly applied. The research includes all the important areas listed above. Several hundred researchers are involved; their work has been highly successful in some cases. There has been a tendency, as in other countries, to de-emphasize fundamental work in favor of shorter-term development projects. The synthesis and development of new polymeric materials for specific applications are very active areas of industrial research at companies such as Marconi, Plessey, Crossfield Electronics, General Electric Co., Raychem (UK), Unitene, Pilkingtons, Kodak (UK), ICI, and BP. The levels of effort are not known, but including development and application research would again involve a total of several hundred scientists, engineers, and supporting staff. Most of the industrial research is carried out without government funding.

General Strategies and Objectives of Research. The overall objectives are to encourage and finance research which will be of the greatest benefit, both short and long term, to British industry and that will meet the needs of the military. Underpinning these more pragmatic objectives, a large body of high-quality fundamental research is funded--mainly at educational institutions.

The general strategy in the UK has been for the government funding agencies, mainly the SERC, to identify important problem areas in polymers and fund them very specifically. In the case of SERC, part of this funding is through the "specially promoted programs" (SPP). In polymers about £1,000,000 was added to the SERC's Materials Committee budget for the period from 1982-83 until 1986-87 for research into polymers with novel optical and electrical properties (area 7 above). This research will be for possible applications for batteries and for various photoelectric, reprographic, and microelectronic devices. Needs which have been identified include: (1) materials research into thin-film microbatteries for microprocessor and display applications, and new resistant coatings for electron and x-ray lithography; and (2) reversible photochromic and particularly photorefractive systems for holographic information storage and photoelectric systems for use in image intensifiers. In addition, anisotropic conductance materials are needed for switching and other devices. These programs are to be interdisciplinary; there will be a coordinator who will work with the scientists, the SERC, and interested government departments, especially the Department of Trade and Industry and the MoD.

In addition to the SPP effort there are SERC grants of about $75,000 to $300,000 for specific subjects at particular universities. Three of the grants are in polymers and cover areas 1a, 3, and 5, above. This funding is in addition to the numerous year-by-year smaller grants of up to, say, $40,000 each spread over 40 to 45 educational institutions.

The emphasis on polymer engineering through SERC/PED, described earlier, covers area 6. The PED program has been very successful; beginning in early 1985 it will be administered by the Plastics and Rubber Institute, essentially a trade organization, but will be otherwise unchanged. The main criterion for PED grants is relevance to industrial needs. The grants are closely monitored with six monthly reviews and visits, and biennial overall reviews and presentations.

Specific projects of particular interest to an agency are supported by separate grants. These are mainly offered by various MoD laboratories, such as RAE, RSRE, PERME, and AWRE. The Ministry of Trade and Industry and the Atomic Energy Agency also support individual projects.

*Federal Republic of Germany*

Scale of Effort and Approximate Funding Levels. Polymer research in the FRG is carried out at universities, in research institutes, and by private industry. Actual funding levels for polymers--or even materials--are difficult to obtain as only overall figures are usually given for groups of subjects. There is a substantial amount of polymer research at about 20 universities plus, say, 10 more with individual efforts. All German universities are government funded, and the research monies are from the Deutsche Forschungsgemeinschaft (DFG), somewhat akin to the US National Science Foundation.

The University of Mainz has by far the largest effort with a DFG "sonderforschungsbereich," or block grant. This was originally for 15 years but has just been extended for another 3 years. The current funding level is DM 3,000,000 (DM 1.00 is about $.37), which helps to support about 150 people, including 16 professors, 10 senior researchers, and many postdoctoral assistants, visiting scientists, graduate students, and support staff. Hamburg University has just formed a new Institute for Technical and Micromolecular Chemistry, absorbing four professors from the former Department of Applied Chemistry

plus three new professorships--one in fiber science, one in technical chemistry, and one in a field still to be decided. This expansion is financed by a grant of DM 5,000,000 from the Hamburg state government, plus DM 35,000,000 for a new building. The group will work closely with the Technical University at Hamburg-Harburg, which has three polymer projects. This will make Hamburg the second largest center for academic polymer research in the FRG.

In addition, Hamburg University coordinates a consortium of researchers in biology and solid state properties of polymers with 16 professors from 12 different universities. The funding, also from the DFG, is DM 2,500,000.

A new Max Planck Institute for Polymers has been created and will get under way in Mainz in September 1984. The directors will be Professor E. Fischer (physics), University of Mainz, and Professor Cr. Wegner (chemistry), University of Frieberg. A third director is presently being recruited. During the first 4 to 5 years (Phase I) there will be 30 academics plus postdoctorals, visiting scientists, and supporting staff, for a total of 110. In the second 4 to 5 year period (Phase II) the staffing will increase by 50 percent. The funding has not yet been revealed.

There are also two other institutes. The Deutsches Kunststoff Institut (DKI), Darmstadt, has a staff of 25 scientists and engineers plus 20 supporting staff. The budget is estimated to be about DM 7,000,000 (it was DM 5,600,000 for 1981).

In Aachen there is the Institut für Kunststoffverarbeitung, which has 65 professionals and 65 supporting staff, with a budget of about DM 9,000,000 (DM 7,600,000 in 1981). Unlike the DKI this institute is entirely for research in polymer engineering and receives one-third of its budget from the state (Nord Rheinpfalz), perhaps one-third from the federal government, and the remainder from private industry.

Polymer research in the FRG, including defense laboratories and private industry, is substantial--but the actual levels could not be ascertained.

Areas With High Priority. These have not been as clearly expressed as by the UK government, but there is a substantial effort in polymer engineering. The FRG's government is also stressing liquid crystalline polymers, both for fibers and for optical, thermal, and other devices. The FRG is emphasizing polymers with interesting optical and, particularly, electrical properties such as conductivity, piezoelectricity, and pyroelectricity. In general, the list of priorities for the UK (pages 1 and 2) is also valid for the FRG. Biological polymers also are of considerable interest in the FRG.

The Role of Government Laboratories, Universities, and Private Industry. The universities play a major role in basic polymer research in the FRG. The government-funded Max Planck Institute for Polymers will also be a major contributor. This institute, the DKI, and the Institut für Kunststoffverarbeitung are the chief government laboratories for polymer research in the FRG. There are also defense and other government laboratories which do not seem to have a very visible effort in high polymers. The large German chemical companies--such as BASF, Hüls, Hoechst, and Bayer--have very large and successful polymer research laboratories and collaborate closely with the universities.

General Strategies and Objectives of Research. There appears to be less conscious effort in the FRG than in the UK to direct polymer research. However, the areas of interest outlined are definitely given high priority in decisions about research funding. University research has remained quite fundamental but is slowly being pushed toward problems of major interest to German industry. The two Kunststoff institutes also reflect this emphasis, which corresponds to some extent to the interest of the UK's PED.

*France*

Scale of Effort and Approximate Funding Levels. As with the FRG, the

funding levels are hard to pinpoint for polymers or are included with materials and even larger groupings. Again the universities, government laboratories, and private industry--particularly the nationalized companies--have a substantial effort in polymer research. About 30 universities have some activity in polymer research. The Centre National de la Recherche Scientifique (CNRS)--similar to the US National Science Foundation--funds individual professors' efforts. When a group is large enough, a block grant is given and a Laboratoire Associé de CNRS is formed, normally at a university but sometimes attached to a government laboratory. In addition (unlike the National Science Foundation), CNRS has its own laboratoires; although there are 200 of these in France, only the one in Strasbourg (Centre de Recherches sur les Macromolécules) is really devoted to polymer research. The laboratory has a staff of about 200; again, the level of funding is not known.

In addition, a number of government laboratories in chemistry and physics sometimes have small polymer sections. Government funding of polymer research is roughly of the same order of magnitude as in the UK.

The research departments of the private and nationalized industries are increasing their efforts in polymer research.

Areas With High Priority. The research areas outlined for the UK and FRG are also major fields in France. Electrically active polymers are given greater emphasis in France than in the FRG or the UK; biologically active and biocompatible polymers and membranes also are being stressed. Engineering research in polymers is not being emphasized as it is in the UK and the FRG.

The Role of Government Laboratories, Universities, and Private Industry. The universities are very active but (with the CNRS-associated centers and Strasbourg) tend to be less independent than in the UK and the FRG. Government support and direction is somewhat stronger than in the other two countries. Although private industry has reasonably good polymer research laboratories, the government-owned and the newer nationalized industries are rapidly becoming very important contributors to French polymer research.

General Strategies and Objectives of Research. Recently the French government has started intervening more directly in planning polymer research. The objective is to meet the needs of French industry and defense. At the same time, France is trying to increase its fundamental research in polymers to boost national prestige. Otherwise, France is pursuing strategies similar to those in the UK and the FRG.

*Comparison of Research in the UK, the FRG, and France*

The overall scale of efforts in the UK and France is probably almost the same; the FRG's effort is about 50 percent larger.

The qualities of research in the UK and FRG are quite comparable. France has some superb efforts, but the quality of the work is less uniform than in the other countries. However, France is working hard to catch up and will undoubtedly succeed within the next few years.

Finally, it should be stated that most of the polymer research topics are quite similar. However, the relative roles of the universities, government laboratories, and industry do vary from country to country.

## Composites

*United Kingdom*

Scale of Effort and Funding Estimates. Composite research is being conducted at about 20 universities, polytechnics, and colleges in the UK. The work is funded by the SERC, mainly through their PED, and by MoD grants. The SERC funding--apart from the PED--is rather limited, and the nonmetallic materials subcommittee has complained about the lack of proposals in the area of composites. It has been rumored, however, that Imperial College will be given a large grant

to set up a composite research center. The level of funding by the SERC and MoD is not clear, but an estimate of about £250,000 is reasonable; the PED funding is about £1,400,000. Thus the estimated total funding for composite research in educational institutions is £1,650,000.

The level of research expenditures in nongovernmental research institutes might be as high as £250,000.

Composite research is also being carried out at a number of government laboratories. At the NPL, a group of about five professionals has a funding of about £200,000.

The Atomic Energy Research Establishment, Harwell, has about five professionals working on composites; the RAE has perhaps 10 scientists plus supporting staff. The funding of these three efforts is not known, but the estimated NPL budget suggests that the figure should be about £600,000. In addition, PERME has a group of about six scientists and engineers conducting composites research, adding approximately £240,000. Thus a rough estimate of the total government funding for composites research in the UK is £3,000,000.

Areas With High Priority. The main activity is in applied industrial and MoD applications of fiber composites. In addition, economical processing of fiber composite materials and fabrication of the materials are being emphasized.

T.-W. Chou (*Fiber Composite Materials Research in the UK: Assessment Report*, ONR, London, Report R-6-83 [24 June 1983]) reported on activities at governmental laboratories, in industry, and at universities. Thermoplastic composites, hybrid fiber and fabric composites, carbon/carbon and ceramic composites, and metal matrix composites were mentioned. The following activities also were identified: environmental degradation, joining, repair and patching, filament winding, and mechanical properties studies. Considerable work is being done in the mechanical properties area, including notch sensitivity and damage tolerance studies, fracture and fatigue, and impact.

R.W. Armstrong (*European Scientific Notes [ESN]*, 37-6:219-222 [1983]) reported that the UK Courtaulds Company accounts for 90 percent of European production of carbon fiber materials with its annual production of 200 tons. An indication of the anticipated growth and use of the product is given by Courtaulds' plan to increase production by 70 percent this year. In a report on the international conference "Science of Ceramics 12" (*ESN* 37-8:321-329 [1983]), Armstrong covered ceramics activities at the AMTE, Holton Health. D.J. Godfry, AMTE, described US-UK development of ceramics for engines and stated that future developments are likely to center on ceramic fiber composites involving silicon nitride, silicon carbide, and zirconia materials.

R.W. Armstrong and J.A. Strada reported on "A German-British Development of a Carbon Fiber Composite (CFC) Taileron for the Anglo-German-Italian Tornado Aircraft," *Military Applications Summary (MAS) Bulletin*, 125 (ONR, London, 4 November 1983). British Aerospace (BAe), Warton, is the UK participant in this activity. The taileron is probably the largest composite component employed thus far in an aircraft structure. In "Second International Conference on Composite Structures," *ESN* 38-2:89-91 (1984), Armstrong mentioned meeting representatives of the Northern Ireland-based Learfan Company; 75 percent of its new airplane is reported to be composed of carbon fiber composites--an outstanding achievement, provided the airplane passes US-imposed test conditions. Satisfying test requirements is a limiting factor to the increased use of composite materials in the UK and elsewhere, as evidenced by the fact that more than 50 percent of the papers at the Second International Conference on Composite Structures were devoted to mechanical and nondestructive testing.

The Role of Government Laboratories, Universities, and Private Industry. The leading development effort is at government laboratories, particularly the RAE and PERME. Next is the industrial effort at companies such as Courtaulds, Dunlop

Ltd., and ICI, which are material suppliers. The university research activity has been concentrated on analysis of properties and testing methods.

T.-W. Chou reported in *ESN* 37-12: 456-458 (1983) that the RAE probably has the highest concentration of research on composites in the UK. The major effort appears to be on testing mechanical properties and modeling the deformation and fracture properties, particularly for impact and fracture mechanics test results. R.W. Armstrong reported in *ESN* 37-6:219-222 (1983) that the Courtaulds polyacrylonitrile has become the dominant starting material for producing Graphil high-strength carbon for high-modulus graphite fiber materials. Carbon fiber reinforced plastic material is in the US McDonnell Douglas F18 airframe, while 26 percent, by weight, of the British AV8 is composed of Graphil-containing carbon/epoxy composite materials. Courtaulds Graphil XAS fibers are in the North Atlantic Treaty Organization's (NATO) Tornado aircraft taileron. At PERME, considerable work has been done with chopped carbon fiber materials to give a deformable composite that is cost-competitive with superplastically deformed metal. This project appears to have been very successful and has been licensed for industrial production.

T.-W. Chou reported in *ESN* 37-6: 217-219 (1983) that a major research effort at ICI has been devoted to polyetheretherketone (PEEK) composite materials; about 15 professional staff members are involved in the work. The ICI "Victrex" PEEK product can be extruded or injection molded. In November 1982, ICI introduced the product Aromatic Polymer Composite (APC-1) as the first commercial, continuous-fiber, thermoplastic preimpregnated composite based on carbon fibers impregnated with PEEK. The APC-1 material is about 10 times tougher than conventional epoxy composites.

General Strategies and Objectives of Research. The following list suggests some of the highlights of the UK's approach to research on composites:

- Primary funding for processing and testing of carbon- or graphite-fiber-reinforced plastic composite materials through the MoD, especially at RAE and PERME.
- UK-FRG cooperation on composites development for the NATO Tornado aircraft--through BAe, Warton, and Messerschmitt-Bölkow-Blohm (MBB), Munich.
- New activity: Group on Aerospace Research and Technology in Europe, involving the RAE, the French Office National d'Études et de Recherches Aérospatiales (ONERA), the Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt eV (DFVLR), and The Netherlands Nationaal Lucht- en Ruimtevaartlaboratorium (NLR)--with a major interest in aerospace-related composites research and development.
- Assessment and development work on composite products from UK industries.
- University research on a broad range of plastic, metal, and ceramic composite systems for supporting knowledge and professional training.

The BAe-MBB cooperation on developing the carbon fiber composite taileron uses the UK Courtaulds fiber material and an epoxy resin from Japan. Further applications of the material are planned for the fuselage, wings, and other secondary structural parts.

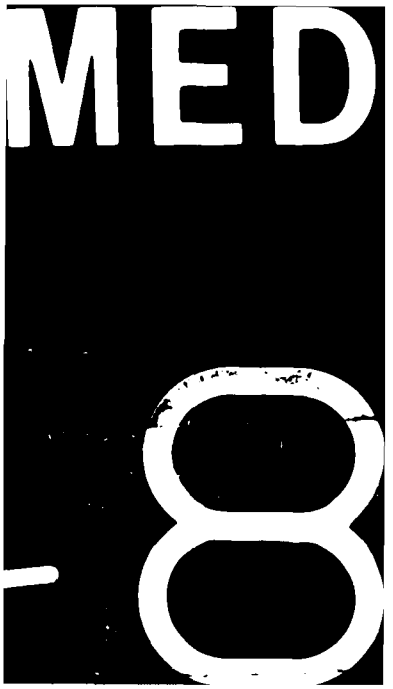
*France*

The following list outlines the scale of France's research effort in composites and provides estimates of funding:

- F 150,000,000 (F 1.00 is about $.13) spent by industry in 1981, amounting to 5 percent of the total industrial research and development budget.
- F 70,000,000 spent by the government in 1981, of which 70 percent was spent by the military; more than F 40,000,000 was spent on aerospace-related composites activities.
- The Ministry of Industry and Research had a budget of F 14,600,000,000 in 1982 to support research and development among 19 major nationalized industries, including four which have

major interests in composites research and development: Pechiney Ugine Kuhlmann--aluminum products; Saint Gobain--glass; Compagnie Générale d'Electicité--electric power; and Elf Aquitaine--petroleum.

- In 1983, the total industrial research budget amounted to F 8,000,000,000, of which more than F 400,000,000 is estimated to have been spent on composites.
- In 1983, the total combined CNRS and Centre de la Energie Atomique budgets amounted to F 1,800,000,000, of which more than F 100,000,000 are estimated to have been spent on composites.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